Durian Seed Starch and Rind Liquid Smoke-Based Edible Coating for Apple Preservation

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Abstract. This study explores the use of an edible coating from durian seed starch combined with liquid smoke derived from durian rind waste for apple preservation. The liquid smoke was prepared through the pyrolysis at three different temperatures: 340°C (T1), 380°C (T2), and 420°C (T3). The edible coatings were formulated by mixing the liquid smoke at concentrations of 2% (C1), 4% (C2), and 6% (C3) with durian seed starch and chitosan. The characteristics of the edible coatings were examined using Fourier Transform Infrared (FTIR) Spectroscopy and X-ray Fluorescence (XRF). Antibacterial properties were tested against *Escherichia coli* and *Staphylococcus aureus*. Additionally, physical and sensory evaluations, including thickness measurement, organoleptic tests, Total Plate Count (TPC), and colorimetric analysis, were conducted to assess the coatings' effectiveness in extending the shelf life of apples. The test results suggest that edible coatings T1C1, T2C2, and T3C3 had good features and met with the Indonesian national standards. The FTIR results identified the optimal edible coating as the combination T3C3, which exhibited significant antibacterial activity, with inhibition zones measuring 14.66 mm for *E. coli* and 6.07 mm for *S. aureus.* The T3C3 coating demonstrated a thickness of 0.031 ± 0.01 mm when applied to apples. After 25 days of storage, the TPC value was 8.1×10^4 CFU/g, indicating that the apples remained within acceptable quality standards. Organoleptic assessments revealed that the T3C3-coated apples maintained their texture, firmness, and aroma for more than 20 days.

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1 Introduction

Ensuring the availability of food is crucial in meeting the expanding needs of Indonesian society. With population growth, there is increasing awareness of health and nutritional patterns, particularly concerning the nutritional value of fruits and vegetables. Post-harvest, efficient handling is critical to maintain fruit quality against chemical, mechanical, physiological, and microbial factors that affect shelf life. Traditional methods using materials such as wax and plastic, while effective, raise concerns over safety and environmental impacts. An environmentally friendly alternative is edible coatings, which form a protective layer to retain moisture and extend shelf life [1,2].

Apples, despite their abundance, have a short shelf life of approximately seven days at temperatures between 20–25°C due to post-harvest physiological changes. These changes, including alterations in color, texture, taste, and wilting, diminish fruit quality and consumer appeal. The inadequacies in post-harvest management necessitate technologies like edible coatings to ensure apple quality until consumption [3].

Edible coatings primarily consist of biopolymers such as lipids, proteins, polysaccharides, and resins. Polysaccharide-based coatings derived from starch, cellulose, alginate, and chitosan are prominent for their natural origins and preservation properties. Research underscores their effectiveness in maintaining fruit quality, with studies exploring materials like canna starch [1]; jackfruit seed starch with glycerol [4]; and taro starch with glycerol [5].

Numerous other natural ingredients show promise as fruit coatings, including polysaccharides from durian seeds [2], which have a high starch content. Research indicates that durian seed starch, with 42.1% starch and significant amylose and amylopectin content, can effectively prolong shelf life without the health risks of synthetic preservatives [6–8]. Edible coatings enhance shelf life by acting as barriers to oxygen and water, improving material quality, and slowing bacterial growth. They inhibit the transfer of gases like CO_2, O_2, and water vapor [9]. However, coatings from durian seed starch have low water resistance. To address this, antimicrobial agents such as liquid smoke from organic biomass [9] and chitosan, a non-toxic polycationic heteropolysaccharide derived from shrimp shells [7] are added.

This study aims to assess edible coatings derived from durian seed and liquid smoke from durian rinds waste, evaluating their efficacy in extending the shelf life of apples.

2 Methodology

2.1 Preparation of liquid smoke

Durian rinds were cut into 3×3 cm pieces and sun-dried for two days. The chips were then subjected to pyrolysis at temperatures of 340°C, 380°C, and 420°C. Detailed procedures for liquid smoke preparation can be found in other sources [10] . The grade 3 liquid smoke obtained from the pyrolysis stage was purified through distillation at 190°C, resulting in grade 1 liquid smoke free from tar [7].

2.2 Starch extraction

Starch was extracted following a modified version of previous procedures [10,11]. Durian seeds were peeled, cut into small pieces, and soaked in sodium metabisulphite for four hours. The chips were washed thoroughly and blended. The blended seeds were mixed with water at a 1:10 ratio, and the mixture was filtered using a cloth to separate the starch solution from

the pulp. The pure durian seed starch solution was left to settle for 24 hours. The resulting starch sediment was dried in an oven at 60°C, ground, and sieved through an 80-mesh sieve.

2.3 Formulation of edible coating

The formulation of edible coating was based on previous research with slight modifications. The coating solution was prepared by mixing the following ingredients: 5% (v/v) glycerol, liquid smoke in variations of 2%, 4%, and 6% (v/v) in 100 ml of distilled water, 0.28 grams of CMC, 1.36 grams of starch, and 1.36 grams of chitosan. First, CMC was dissolved in the homogenized liquid smoke and distilled water mixture, which was then heated on a hot plate at 70°C. Starch and chitosan were gradually added while stirring continuously, followed by 5 ml of glycerol. The mixture was stirred with a magnetic stirrer until homogeneous. Apples were dipped into the edible coating solution for 60 seconds and then dried in an oven at 35°C for 2 hours. The coated apples were subjected to various tests.

2.4 Examinations of edible coatings and shelf life

2.4.1 Characterization
The edible coating samples were examined using FTIR (Thermoscientific Nicolet iS-10) to identify functional groups, and XRF (S2 PUMA-Bruker) to determine the components within the edible coating.

2.4.2 Organoleptic Test
This sensory evaluation involved using the senses to assess the texture (by hands or tongue), color (by eyes), and smell (by nose) of the coated apples. The evaluation was conducted by 15 panelists, who rated their preference on a scale of 1 to 5 (1 = dislike, 2 = somewhat dislike, 3 = neutral, 4 = like, 5 = strongly like).

2.4.3 Color test
Color analysis was performed at the selection of fresh apples for use as samples and after coating with the edible film. This analysis aimed to detect physical or chemical changes in the product. A colorimeter was used to measure the color, based on blue, red, and green components of light captured by the sample. The device provided readings in terms of L (brightness), a (redness), and b (yellowness) values [9].

2.4.4 Thickness test
The thickness of the edible coating was measured using a micrometer with 0.01 mm accuracy. The diameter of the uncoated apples was measured at three different points, and the same points were measured again after coating. The difference in measurements before and after coating represented the thickness of the edible coating. The results were recorded and averaged.

2.4.5 Antibacterial test
Antibacterial activity was assessed using the disk diffusion method (Kirby-Bauer test. The detailed technique for antibacterial activity tests can be obtained elsewhere [10]. Statistical analysis was performed using the Least Significant Difference (LSD) method with SPSS version 26.

2.4.6 Total Plate Count (TPC) test
TPC test, a criterion for product quality, determines the bacterial colony count in a sample. It was conducted following the previous research [10].

3 Results and Discussion

3.1 FTIR Test

FTIR is a method used to identify the functional groups present in a material. This test is based on the interaction between infrared radiation and the molecules of the material. Each functional group has a unique infrared resonance pattern, which can be used to identify those functional groups. The purpose of the FTIR analysis is to understand the mixing process, whether it occurs physically or chemically [8]. Figures 1–3 present the FTIR test results of the edible coating with various combinations and treatments.

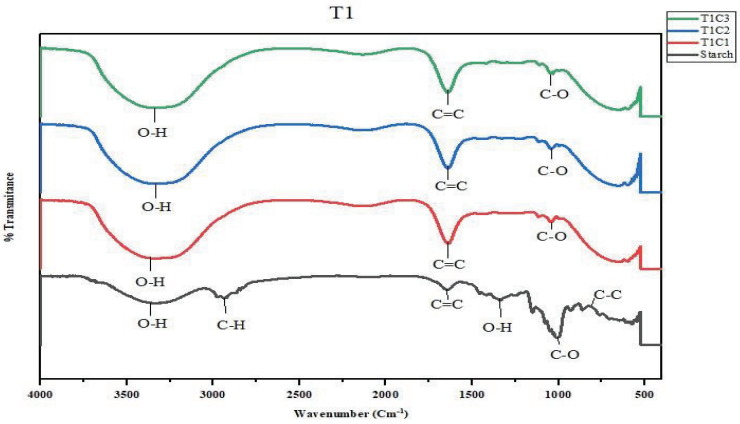

Fig. 1. Compound groups in 340°C liquid smoke: a. T1C1 2% (v/v) liquid smoke b.T1C2 4% (v/v) liquid smoke c. T1C3 6% (v/v) liquid smoke.

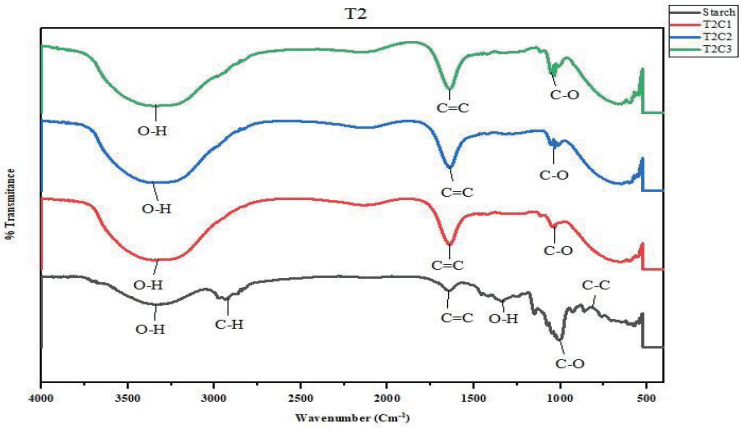

Fig. 2. Compound groups in 380°C liquid smoke: a. T2C1 2% (v/v) liquid smoke b.T2C2 4% (v/v) liquid smoke c. T2C3 6% (v/v) liquid smoke.

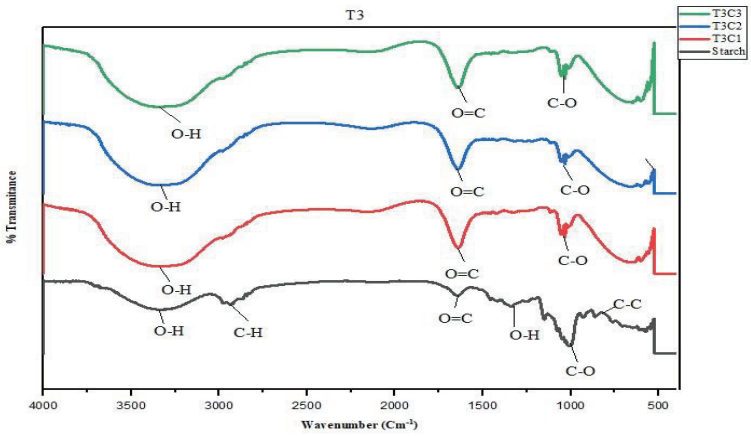

Fig. 3. Compound groups in 420°C liquid smoke: a. T3C1 2% (v/v) liquid smoke b. T3C2 4% (v/v) liquid smoke c. T3C3 6% (v/v) liquid smoke.

Figure 1 shows the FTIR analysis results of durian seed starch with a wavenumber of 3340 cm^{-1} indicating the presence of O-H groups, 2928 cm^{-1} indicating C-H alkane groups, and 1640 cm^{-1} indicating C=C alkene groups. The numbers 1335 cm^{-1}, 997 cm^{-1}, and 819 cm^{-1} represent O-H (alcohol), C-O (starch group), and C-C groups, which are characteristic of starch [12,13]

Figures 1–3 present the FTIR test results on the modified edible coating of durian seed starch with varying concentrations and pyrolysis temperatures of liquid smoke. There were no significant differences in the functional groups obtained, with each concentration and temperature resulting in O-H (alcohol), C=C (alkene), and C-O (starch) groups. The formation of C-O groups indicates that interactions occur between amylose and amylopectin. The FTIR analysis results on the durian seed edible coating with liquid smoke addition showed no new functional groups. Previous research on edible films with the addition of galangal essential oil also found no new functional groups, maintaining the properties of its constituents [14]. This suggests that the coating process involves physical mixing rather than chemical changes [10]. These findings align with previous research [9] which also found no new functional groups in edible coatings made from durian seed starch with varying glycerol concentrations, indicating physical mixing of the functional groups.

3.2 XRF Test

XRF analysis is a crucial technique for determining the chemical composition of materials, useful in scientific research. This method allows for the identification and quantification of various chemical [15]. XRF is a flexible, non-destructive analytical technique capable of detecting elements down to parts per million (ppm) levels.

Table 1. XRF test results on edible coatings.

Element / Concentration (Wt%)	starch	T1C1	T1C2	T1C3	T2C1	T2C2	T2C3	T3C1	T3C3
MgO	11.32	18.82	18.64	20.19	20.19	19.18	18.93	20.64	20.53
SiO_2	10.70	12.78	11.77	13.94	13.94	10.78	11.94	11.50	12.13
P_2O_5	31.81	28.48	29.13	27.44	27.44	28.96	28.71	28.02	28.24
SO_3	16.67	15.60	15.59	14.96	14.96	15.11	16.49	15.05	14.91
Cl	10.06	12.97	12.97	13.37	13.37	14.62	13.50	12.92	14.07
K_2O	4.47	3.49	4.07	2.97	2.97	3.49	3.24	3.88	3.19
CaO	14.93	7.83	7.80	7.09	7.09	7.83	7.16	7.96	6.90

Table 1 indicates seven different compound compositions present in durian seed starch and the edible coating solution. The elemental compositions in the edible coating solution did not significantly differ across the various formulations. The compound with the highest concentration in durian seed starch was P_2O_5 (phosphorus pentoxide) at 31.81%, and similarly, in the edible coating solution, it ranged from 27.44% to 2.13%. SO_3 (sulfur trioxide) was the second-highest concentration compound in durian seed starch at 16.67%, whereas MgO (magnesium oxide) was the second highest in the edible coating solution, ranging from 18.64% to 20.64%. The concentrations of elements in the edible coating formulations did not show significant variations.

3.3 Organoleptic Test

3.3.1 Aroma

Aroma is a critical element in organoleptic testing, engaging the sense of smell. The aroma in a foodstuff will be easily detectable by the senses when the food materials has distinctive aroma characteristics.

Table 2 suggests that the application of durian seed starch-based edible coatings with liquid smoke concentrations of 2%, 4%, and 6% (v/v) at pyrolysis temperatures of 340°C, 380°C, and 420°C affected the aroma of apples. Higher temperatures and concentrations prolonged the apple's aroma. Uncoated apples maintained their aroma for 15 days, while coated apples retained their aroma for up to 20 days. The optimal result was observed under the T3C3 condition, indicating that higher concentrations of liquid smoke and higher pyrolysis temperatures used in the edible coating extended the aroma retention in apple samples. The formation of alcohol-like aromas is due to increased respiration rates and ethylene production during ripening [11]. One-Way ANOVA tests showed significant differences in the edible coatings from durian seed starch with the addition of liquid smoke pyrolyzed at 340°C, 380°C, and 420°C on the aroma of apple samples. This finding was further supported by LSD tests, which also indicated significant differences.

Table 2. Aroma assessment results on apple samples with edible coating.

Storage time (Day)	Liquid Smoke Concentration (%)	Organoleptic Test Results			Control
		340°C	380°C	420°C	
5	2	5.00 ± 0.00^{A}	5.00 ± 0.00^{A}	5.00 ± 0.00^{A}	5.00 ± 0.00^{A}
	4	5.00 ± 0.00^{A}	5.00 ± 0.00^{A}	5.00 ± 0.00^{A}	
	6	5.00 ± 0.00^{A}	5.00 ± 0.00^{A}	5.00 ± 0.00^{A}	
10	2	4.07 ± 0.25^{B}	5.00 ± 0.00^{C}	5.00 ± 0.00^{C}	4.27± 0.25^{A}
	4	5.00 ± 0.00^{C}	5.00 ± 0.00^{C}	5.00 ± 0.00^{C}	
	6	5.00 ± 0.00^{C}	5.00 ± 0.00^{C}	5.00 ± 0.00^{C}	
15	2	4.00 ± 0.00^{B}	4.93 ± 0.00^{B}	5.00 ± 0.46^{C}	3.27 ± 0.46^{A}
	4	4.00 ± 0.00^{B}	4.93 ± 0.00^{B}	5.00 ± 0.00^{C}	
	6	4.00 ± 0.00^{B}	5.00 ± 0.46^{C}	5.00 ± 0.00^{C}	
20	2	3.00 ± 0.00^{B}	4.00 ± 0.00^{C}	4.33 ± 0.48^{C}	2.33 ± 0.00^{A}
	4	3.00 ± 0.00^{B}	4.00 ± 0.00^{C}	4.93± 0.00^{C}	
	6	3.00 ± 0.00^{B}	4.93 ± 0.00^{C}	5.00 ± 0.00^{D}	
25	2	2,00 ± 0,00^{B}	3,00 ± 0,00^{C}	4,00 ± 0,00^{D}	1,33 ± 0,00^{A}
	4	2,00 ± 0,00^{B}	3,00 ± 0,00^{C}	4,00 ± 0,00^{D}	
	6	2,00 ± 0,00^{B}	3,00 ± 0,00^{C}	4,93± 0,00^{D}	

Note: 5 = No smell, 4 = Slight smell, 3 = Moderate, 2 = Smelly, 1 = Very smelly

3.3.2 Texture

Texture testing evaluates and measures the physical or mechanical characteristics of a material or product, such as strength, hardness, softness, elasticity, or other mechanical properties. Texture testing is generally conducted manually, involving tactile assessment [16].

As seen in Table 3, the texture of apples was maintained for approximately 20 days, while coated apples retained their texture for up to 25 days. The optimal condition was found in the T3C3 treatment. The softening of apples, indicated by texture changes, is due to cell wall degradation accelerated by microbial activity [11]. One-Way ANOVA tests demonstrated significant differences in the texture of durian seed starch-based edible coatings with liquid smoke from the 340°C, 380°C, and 420°C pyrolysis across various treatments on apple samples. This result was supported by LSD tests, which also showed significant differences.

The hardness degradation of coated apples was slower compared to uncoated apples, indicating that the coating effectively maintained apple texture [1].

Table 3. Texture assessment results on apple samples with edible coating.

Storage time (Day)	Liquid Smoke Concentration (%)	Organoleptic Test Results			Control
		T1	T2	T3	
5	C1	4.00 ± 0.00^{A}	4.00 ± 0.00^{A}	4.00 ± 0.00^{A}	4.00 ± 0.00^{A}
	C2	4.00 ± 0.00^{A}	4.00 ± 0.00^{A}	4.00 ± 0.00^{A}	
	C3	4.00 ± 0.00^{A}	4.00 ± 0.00^{A}	4.00 ± 0.00^{A}	
10	C1	4.00 ± 0.00^{A}	4.00 ± 0.00^{A}	4.00 ± 0.00^{A}	4.00 ± 0.00^{A}
	C2	4.00 ± 0.00^{A}	4.00 ± 0.00^{A}	4.00 ± 0.00^{A}	
	C3	4.00 ± 0.00^{A}	4.00 ± 0.00^{A}	4.00 ± 0.00^{A}	
15	C1	3.93 ± 0.00^{B}	4.00 ± 0.00^{C}	4.00 ± 0.00^{C}	3.47 ± 0.51^{A}
	C2	4.00 ± 0.00^{C}	4.00 ± 0.00^{C}	4.00 ± 0.00^{C}	
	C3	4.00 ± 0.00^{C}	4.00 ± 0.00^{C}	4.00 ± 0.00^{C}	
20	C1	3.53 ± 0.51^{B}	3.87 ± 0.35^{C}	4.00 ± 0.00^{C}	3.00 ± 0.00^{A}
	C2	3.87 ± 0.35^{C}	3.93 ± 0.00^{C}	4.00 ± 0.00^{C}	
	C3	3.93 ± 0.00^{C}	4.00 ± 0.00^{C}	4.00 ± 0.00^{C}	
25	C1	2.27 ± 0.45^{B}	3.00 ± 0.00^{C}	3.33 ± 0.48^{C}	2.27 ± 0.45^{A}
	C2	2.33 ± 0.40^{B}	3.00 ± 0.00^{C}	4.00 ± 0.00^{D}	
	C3	2.47 ± 0.51^{B}	3.00 ± 0.00^{C}	4.00 ± 0.00^{D}	

Note: 4 = hard, 3 = slightly soft, 2 = somewhat soft, 1 = soft

3.3.3 Color test

Initial food assessments are often based on color, which can be perceived visually before touching or consuming the food. Color not only provides visual information about appearance and cleanliness but also serves as an indicator of chemical changes in the food. Therefore, color is a significant determinant in evaluating the edibility of food items. This color test was conducted only at a 6% liquid smoke concentration (C3) across various pyrolysis temperatures.

Table 4. Color test results on apple samples with edible coatings.

Storage time (Day)	Parameter	Color Test Result		
		T1C3	T2C3	T3C3
0	Color L	42.86	38.20	38.79
5		40.33	36.21	37.54
10		37.84	34.20	36.29
15		35.32	32.18	35.04
20		32.85	30.19	33.79
25		30.37	28.18	32.54
0	b	32.53	27.69	29.81
5		30.33	25.69	28.81
10		28.13	23.69	27.81
15		25.93	21.69	26.81
20		23.73	19.69	25.81
25		21.53	17.69	24.81
0	a	5.59	4.8	4.39
5		4.99	4.4	4.14
10		4.39	4	3.89
15		3.79	3.6	3.64
20		3.19	3.2	3.39
25		2.59	2.8	3.14

3.3.3.1 Brightness (L)

Table 4 shows the color test results using a colorimeter, indicating that the apples with the T3C3 treatment exhibited the least reduction in color brightness. The edible coating with T3 inhibited browning for longer due to the higher acid content in the liquid smoke at higher pyrolysis temperatures compared to T1C3 and T2C3. The sample with the highest brightness reduction was T1C3, owing to its lowest acid content. Higher acid content in the edible coating correlates with lower brightness reduction. The acid in the sample reduces pH level, inactivating polyphenol oxidase enzymes and inhibiting browning, thus maintaining the bright color of the apples [17].

3.3.3.2 Red-green color (a)

From Table 4, it is evident that the ‘a’ parameter values decreased over storage time, suggesting a decline in the correlation between the greenish color of apples and storage duration. Color changes during storage result from respiration processes that alter the fruit’s pigments [3]. Previous study [7] found that the ‘a’ parameter is not strongly associated with polyphenol oxidase enzymes, while only the L (brightness) value is linked to inhibiting polyphenol oxidase activity.

3.3.3.3 Yellow-blue color (b)

Table 4 shows positive values, indicating that all samples tended toward yellow. The longer the storage time, the lower the ‘b’ value due to the apples’ color change. Similar to the ‘a’ value, the ‘b’ value is unrelated to polyphenol oxidase enzymes but affects the L value as a polyphenol enzyme inhibitor [3].

Over extended storage periods, apple color brightness and greenish hues decrease, while the yellow hue increases. Color changes in apples during storage are due to respiration processes that alter the pigments in the fruit [14].

3.4 Thickness Test

The thickness test measures the dimension or thickness of a material or layer. In the context of food, this refers to measuring the thickness of the edible coating applied to food products. This test is crucial to ensure that the thickness of the material or layer complies with certain requirements or standards.

Table 5. Thickness Test Results on Apple Samples with Edible Coating.

Liquid Smoke	Thickness (mm)		
	C1 (2%)	C2 (4%)	C3 (6%)
T1	0.013 ± 0.01	0.022 ± 0.01	0.031 ± 0.01
T2	0.013 ± 0.01	0.022 ± 0.01	0.031 ± 0.01
T3	0.013 ± 0.01	0.022 ± 0.01	0.031 ± 0.01

The thickness of the edible coating from durian seed starch with added liquid smoke is presented in Table 5, ranging from 0.013 to 0.031 mm. It can be observed that the different pyrolysis temperatures of the liquid smoke do not result in variations in thickness. However, the concentrations of liquid smoke, namely C1, C2, and C3, do show differences, with respective thicknesses of 0.013, 0.022, and 0.031 mm. Previous research [18] on carrageenan and liquid smoke edible films showed a thickness range of 0.12–0.16 mm, while another study [19] found that the thickness of edible films from oil palm trunk starch ranged from 0.15–0.19 mm. The maximum allowable thickness for edible films is 0.25 mm [20]. The thickness of the edible coating in this study meets the JIS standard. This is consistent with previous research [17], which indicated that higher concentrations of liquid smoke lead to increased thickness of the edible coating due to compounds like phenols and carboxylic acids forming hydrogen bonds. These bonds increase the solution's viscosity, making it thicker and more capable of forming a film [21].

3.5 Antibacterial Activity Test

The antibacterial activity test of the edible coating solution in this study used two types of bacteria: the gram-negative *E. coli* and the gram-positive *S. aureus*. These bacteria are known pathogens that can cause spoilage in fruits. The antibacterial activity was evaluated by observing the clear zones around bacterial colonies on paper discs. The diameter of the inhibition zones for each treatment is presented in Table 6.

Table 6 shows that both bacteria exhibit different sensitivities to the edible coating solution. It is notable that the pyrolysis temperature, liquid smoke concentration, and chitosan concentration in the solution have a proportional relationship with the size of the inhibition zones produced. This study notes that higher pyrolysis temperatures result in increased concentrations of phenolic compounds, carbonyls, and organic acids, and higher chitosan concentrations enhance antibacterial efficacy, effectively inhibiting the growth of pathogenic bacteria [22] The response to microbial growth inhibition is categorized by the diameter of the inhibition zones: more than 20 mm indicates very strong inhibition, 11–20 mm indicates strong inhibition, 6–10 mm indicates moderate inhibition, and clear zones less than 5 mm indicate weak inhibition [23]. Previous research using rice husk liquid smoke showed

stronger antibacterial activity against *S. aureus* compared to *E. coli*, with higher concentrations leading to larger inhibition zones [10]. From Table 6, the antibacterial property against *S. aureus* is classified as moderate inhibition with inhibition zone diameters ranging from 6.02–6.07 mm. In contrast, *E. coli* shows very strong inhibition with zone diameters ranging from 12.22–15.25 mm. These results are consistent with previous studies, that tested the antibacterial activity of galam wood liquid smoke and chitosan against similar bacteria, demonstrating that liquid smoke and chitosan are more effective against gram-negative bacteria compared to gram-positive bacteria, with inhibition zones in the moderate category [14]. The antibacterial mechanism of liquid smoke involves phenols increasing cell membrane permeability, leading to cell content leakage and essential enzyme inactivation. Acetic acid acidifies the cytoplasm, damaging membrane surface tension and inhibiting active food transport, thus destabilizing various cellular functions and structures.

Table 6. Antibacterial activity test results of edible coatings

Bacteria	Sample	Inhibition Zone (mm)		
		T1	T2	T3
S. aureus	Distilled water	0.00 ± 0.00^{A}	0.00 ± 0.00^{A}	0.00 ± 0.00^{A}
	C1	6.01 ± 0.02^{B}	6.03 ± 0.02^{B}	6.05 ± 0.02^{B}
	C2	6.02 ± 0.01^{B}	6.07 ± 0.02^{B}	6.06 ± 0.01^{B}
	C3	6.02 ± 0.02^{B}	6.07 ± 0.02^{B}	6.07 ± 0.01^{B}
	Vancomycin	16.34 ± 0.32^{C}	15.17 ± 0.56^{C}	16.09 ± 007^{C}
E. coli	Distilled water	0.00 ± 0.00^{A}	0.00 ± 0.00^{A}	0.00 ± 0.00^{A}
	C1	12.22 ± 0.05^{B}	13.17 ± 0.05^{B}	13.16 ± 0.18^{B}
	C2	13.66 ± 0.06^{C}	13.32 ± 0.06^{B}	14.52 ± 0.08^{C}
	C3	15.25 ± 0.06^{D}	13.54 ± 0.09^{C}	14.66 ± 0.30^{C}
	Gentamicin	23.36 ± 0.34^{E}	23.51 ± 0.11^{D}	21.09 ± 0.07^{D}

3.6 Total Plate Count (TPC) Test

The TPC method measures the total number of microorganisms, including fungi, yeast, and bacteria, that grow on agar media under specific conditions, such as time and temperature. The TPC standard for foodstuff sets a maximum value of 1×10^5 or 5 log CFU/g according to Indonesian National Standard 02-2725-1992 [24].

Table 7. TPC of edible coatings with varying liquid smoke concentrations at 340°C.

Pyrolysis Temperature (°C)	Storage time (Day)	Total Plate Count (CFU/g)			
		Liquid Smoke Concentration			
		Blank	C1	C2	C3
T1	10	$<1\times10^3$	1.1×10^5	9.4×10^3	7.2×10^4
	20	1.7×10^3	1.8×10^5	1.5×10^5	9.9×10^4
	25	2.7×10^3	2.5×10^5	2.8×10^5	20×10^5
	30	7.3×10^3	4.7×10^5	4.2×10^5	21×10^5

Table 8. TPC of edible coatings with varying liquid smoke concentrations at 380°C.

Pyrolysis Temperature (°C)	Storage time (Day)	Total Plate Count (CFU/g)			
		Liquid Smoke Concentration			
		Blank	C1	C2	C3
T2	10	$<1\times10^3$	8.1×10^4	2.8×10^4	45×10^4
	20	1.7×10^5	15×10^5	13×10^5	22×10^4
	25	2.7×10^5	23×10^5	19×10^5	32×10^5
	30	7.3×10^5	37×10^5	35×10^5	55×10^5

Table 9. TPC of edible coatings with varying liquid smoke concentrations at 420°C.

Pyrolysis Temperature (°C)	**Storage time (Day)**	**Total Plate Count (CFU/g)**			
		Liquid Smoke Concentration			
		Blank	**C1**	**C2**	**C3**
T3	10	$<1\times10^3$	8.2×10^3	$<1\times10^3$	3.0×10^3
	20	1.7×10^3	2.3×10^4	5.0×10^4	1.9×10^4
	25	2.7×10^3	8.1×10^4	12×10^5	8.1×10^4
	30	7.3×10^3	34×10^5	16×10^5	18×10^5

Tables 7, 8, and 9, indicate that higher pyrolysis temperatures and higher concentrations of liquid smoke result in fewer colonies in the samples. Previous research found that edible coatings from aloe vera on apple slices were no longer suitable for consumption after three days of storage due to exceeding the total plate count standard [14]. In the present study, whole apples were used. The data indicate that T3C3 liquid smoke can maintain apple freshness for a longer period. Liquid smoke inhibits bacterial growth due to phenolic, acidic, and carbonyl compounds that work together to prevent degradation and spoilage [10]. Liquid smoke also has antioxidant, antibacterial, and anti-inflammatory properties. The characteristics of liquid smoke, such as acidity, are influenced by the pyrolysis temperature. Phenol and guaiacol are the main components of liquid smoke, and their concentrations increase with higher pyrolysis temperatures [2].

4 Conclusions

FTIR test results indicated no new functional groups in the edible coating derived from durian seed starch with various concentrations of liquid smoke, suggesting that only physical mixing occurred. XRF analysis revealed that the highest composition in durian seed starch was P_2O_2 at 31.81%, followed by SO_3 at 16.67%. In the edible coating solution, the dominant compounds were P_2O_2 (27.44–29.13%) and MgO (18.64–20.64%). The T3C3 edible coating was most effective in preserving apple freshness. Antibacterial tests demonstrated satisfactory results for *E. coli* and *S. aureus*, with inhibition zones of 14.66 mm and 6.07 mm, respectively. Apple texture and aroma were maintained for over 20 days with a coating thickness of 0.031 ± 0.01 mm. The apples also retained a fresh appearance for up to 30 days.

Based on the TPC test, apple freshness was sustained for up to 25 days, with a TPC value of 8.1×10^4 CFU/g, compliant with the Indonesian national standards.

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